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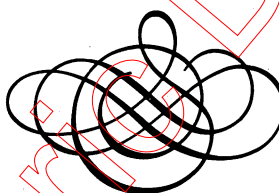
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Alcohol Production from Agricultural Products:

An Update on the Facts and Issues



COOPERATIVE EXTENSION SERVICE, PURDUE UNIVERSITY, WEST LAFAYETTE, IN

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Alcohol Production from Agricultural Products: An Update on the Facts and Issues

Otto C. Doering III and Wallace E. Tyner*

Why is it that people suddenly are interested in alcohol production? There are two reasons. First, we are finally recognizing the nature of our most immediate energy problem; and second, OPEC countries have recently changed the economics of oil as compared with potential oil substitutes.

While the United States is blessed with abundant supplies of coal, it has only a limited quantity of oil. Thus, the critical need is for liquid fuels. Almost half of the energy we consume is liquid--in the form of petroleum--yet less than 5 percent of our own energy resources are in the form of petroleum. As a consequence, we are importing almost one-half of our liquid fuel requirements.

Recent oil price increases have pushed the price of petroleum to the point where alcohol production may soon make sense economically, even without government subsidies. Shale oil and coal liquefaction are still more expensive, but the gap is being narrowed rapidly. The liquid fuel problem is so severe that it may well be in our best national interest to embark on the production of non-petroleum liquid fuels even if they are more expensive than imported oil.

However, if an alternative liquid fuels program is carried out, we must recognize that even on a massive scale, such a program would require many years of effort before its effect on the high volume of oil we import will be felt. This can only be accomplished by a long term, deliberate and thoughtful combination of research and development of alternative fuel sources, coupled with a demanding conservation program for available and existing liquid fuel materials.

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FUEL FROM AGRICULTURAL MATERIAL

There are a number of possibilities for converting agricultural products or wastes to liquid fuels. The choice of raw materials and processes is complex and involves a number of important policy choices. Only recently have we had real incentives to pursue such activities, so many of the economic and technical questions still remain unanswered. There are also a number of political issues remaining to be solved as well. The intent of this publication is to present facts, to identify some of the issues and to raise some important economic and technical questions that need to be asked to better understand the actual potential of those solutions.

This publication first provides some definitions of common terms and a set of conversion factors that are useful in looking at different alcohol production processes. It then looks at the production of grain alcohol for blending with gasoline to make gasohol. Finally, it looks at the cellulose conversion alternative of utilizing agricultural by-products (such as corn stalks, cellulose wastes and old newspapers) to make ethanol.

The economic and technical issues in the cellulose conversion process are sufficiently different from grain conversion to warrant an entirely separate discussion. Cellulose conversion technology may be available to us on a commercial scale within a few years. The construction of grain conversion capacity should be considered in the context of moving to cellulose conversion technology down the road.

DEFINITIONS AND CONVERSION RATIOS

Alcohols: A group of organic chemical compounds composed of carbon, hydrogen and oxygen.

Methanol (methyl alcohol, also known as wood alcohol): CH_3OH , one of the alcohols which has been proposed for blending with gasoline. However, methanol gasoline blends are more corrosive than ethanol blends.

Ethanol (ethyl alcohol): $\text{C}_2\text{H}_5\text{OH}$, the alcohol product of grain fermentation used in alcoholic beverages and for industrial purposes. It is proposed for blending with gasoline to make gasohol. At present, industrial ethanol is primarily produced from petroleum.

Gasohol: A blend of gasoline and alcohol (usually ethanol), commonly discussed as a product composed of 90 percent gasoline and 10 percent ethanol by volume.

Proof: Alcoholic concentration indicated by a number that is twice the percent by volume of alcohol present. Industrial ethanol is usually 190 proof (95% alcohol), and ethanol for gasohol is 200 proof (100% alcohol). Volume and weight percent are not equivalent.

Distillers Grain: A by-product of the grain fermentation process which may be used as a high protein animal feed.

Cellulose: A sugar polymer found in the woody parts of plants (e.g., corn stalks).

Fermentable Sugar: Sugar (usually glucose) derived from starch and cellulose which can be converted easily to alcohol.

Conversion Ratios

- 1 barrel equals 42 gallons.
- 1 bushel of corn weighs 56 pounds.
- 1 gallon of ethanol @ 200 proof weighs 6.6 pounds at room temperature.
- 1 gallon of ethanol contains 85,000 BTUs @ 200 proof.
- 1 gallon of No. 2 diesel fuel contains 140,000 BTUs.
- 1 gallon of gasoline contains 124,000 BTUs.
- 1 ton of crop residue contains the potential for 0.8 ton of fermentable sugar.
- 1 ton of fermentable sugar can yield up to 0.5 ton of 200 proof ethanol.

In the production of grain alcohol:

- 1 bushel of corn yields up to 2.57 gallons of 200 proof ethanol.
- 1 bushel of corn yields 16.3 pounds of carbon dioxide.
- 1 bushel of corn yields almost 17 pounds (when dried) of distillers grain at 27% protein.

GRAIN FERMENTATION FOR GASOHOL

There is much publicity currently about gasohol. Actually, gasohol is not a new con-

cept or product. In 1934, Hiram-Walker marketed a motor fuel product called Alcolene, which was a blend of alcohol and gasoline. Since the early 1930s, the relative price of gasoline fell because of inexpensive petroleum supplies, and blending alcohol with gasoline became unprofitable. This is now changing.

On the agricultural side, with the record corn crops and with export embargos from time to time, we can face the prospect of occasional surpluses and falling grain prices. Government is continually conscious of the need to increase farm income or at least keep it from falling too far.

Gasohol emerges as an apparently attractive solution to both the agricultural and energy problems. Utilizing corn to produce alcohol can help stabilize grain prices by countering the effects of embargos and record yields. Federal subsidies for alcohol production would reduce the need for direct government programs to increase grain prices. In terms of energy, the alcohol supply would be blended on a 10 to 20 percent basis with gasoline, thereby reducing our need to import as much oil from abroad.

Some Economic Considerations

Why not have a plan which solves the agricultural surplus problem and aids in reducing our energy imports? Why haven't we implemented such a plan already? There are some sound economic reasons why we haven't been committing ourselves to large scale alcohol production until recently.

Table 1 illustrates what the economics of gasohol were in the beginning of 1978. In this example, ethanol could be produced for about \$1.00 a gallon, which was 2 1/2 to 3 times the refinery price of gasoline.

In order to make gasohol production economical, therefore, the federal tax of \$.04 per gallon was exempted on all gasohol sold. Since one gallon of ethanol was mixed with nine gallons of gasoline to make ten gallons of gasohol, and since each gallon of gasohol received the \$.04 tax break, this is equivalent to a \$.40 subsidy per gallon of alcohol.

This meant that if the refinery price of gasoline rose to within \$.40 of the cost of alcohol, gasohol would be an economical proposition with the federal tax subsidy. This had not occurred in 1978, so a number of states removed their road taxes to give further subsidy to gasohol.

In early 1980 when President Carter announced his gasohol program, the refinery price of gasoline was around \$.90 a gallon. Table 2 shows how the economics of gasohol

Table 1. Price Comparison for Gasoline and Gasohol, January 1978.

Item	Gasoline	Gasohol*
Gasoline @ \$.38/gal at refinery	.38	.34
Ethanol @ \$1.00/gal at refinery	--	.10
Transportation	.03	.03
Station mark-up	.09	.09
State tax	.08	.08
Federal tax	.04	.04
Pump price of product	.62	.68

* A mixture containing 90 percent gasoline and 10 percent ethanol.

Table 2. Price Comparison for Gasoline and Gasohol, January 1980 (Indiana).

Item	Gasoline	Gasohol*
Gasoline @ \$.90/gal at refinery	.90	.81
Ethanol @ \$1.60/gal at refinery**	--	.16
Transportation and handling	.04	.05
Station mark-up	.10	.10
State tax	.08	.04
Federal tax	.04	--
Pump price of product	1.16	1.16

* A mixture containing 90 percent gasoline and 10 percent ethanol.

** Ethanol was selling for \$1.60/gal. because of high demand. Its cost of production was probably around \$1.20/gal.

looked then, after the rapid increases in OPEC oil prices. It is clear from this table that the remission of the \$.04 federal tax is by itself almost sufficient to make gasohol prices competitive, especially if one expects the refinery price of gasoline to be well over \$1.00 by mid-1980. When the refinery price gets over \$1.25 in this example, the remission of the Indiana state sales tax is no longer necessary to make gasohol price competitive with gasoline, even with \$1.60 ethanol.

Assuming the use of gasohol nationwide, the federal subsidy is still substantial. We consume about 110 billion gallons of gasoline annually. If \$.04 tax is exempted from each gallon, the total value of this subsidy is \$4.4 billion or \$20.00 for each person in the country.

Another important question is, "How much grain would be required to produce the ethanol needed to make a 10 percent alcohol-90 percent gasoline blend for the nation's consumption?" To make the 11 billion gallons of alcohol required, it would take 4.3 billion bushels of corn, about 60 percent of the nation's corn crop. This would require a drastic change in our livestock industry and eliminate most exports of corn. The long term question is, "To what extent are we willing to expand our ethanol production industry with just grain as a base for this expansion?" It is here that

the potential for cellulose conversion to alcohol becomes critically important.

It is also helpful to examine the breakdown of the cost of production for corn fermentation ethanol. Table 3 provides the cost breakdown for a range of corn prices from \$1.50 to \$4.00 per bushel. The total cost of production of corn fermentation alcohol (plant, fuel, labor, interest, etc.) is about \$1.62 per gallon with corn at \$2.50 a bushel, including capital recovery. Credits for by-products such as dried distillers grain (DDG) amount to \$.39 per gallon. (All calculations are done for a plant producing 50 million gallons of ethanol annually.)

Note that the value of DDG may be on the high side if nearby markets are not available or if by-product prices should fall with increasing output. It may be on the low side if DDG prices rise with corn prices.

The annual corn requirement for the plant is 19.5 million bushels. As can be seen from Table 3, ethanol corn price combinations range from \$1.50 corn yielding \$.93 ethanol to \$4.00 corn yielding \$1.63 ethanol. The alcohol price for \$2.50 corn is \$1.21 per gallon.

The Question of Energy Efficiency

Another consideration that has created considerable interest is the net energy ef-

Table 3. Cost of Producing Alcohol from Corn.*

Corn price	Corn cost ^a	Fixed costs ^b	Operating costs ^c	Gross total cost	By-product credits ^d	Minimum alcohol selling price
\$/bu.	\$/gal.	\$/gal.	\$/gal.	\$/gal.	\$/gal.	\$/gal.
1.50	.58	.31	.31	1.20	.27	.93
2.00	.78	.31	.31	1.40	.33	1.07
2.50	.97	.31	.31	1.59	.38	1.21
3.00	1.17	.31	.31	1.79	.44	1.35
3.50	1.36	.31	.31	1.98	.49	1.49
4.00	1.56	.31	.31	2.18	.55	1.63

SOURCE: the raw data for compiling this table were obtained from Grain Motor Fuel Alcohol-Technical and Economic Assessment Study, prepared for the U.S. Department of Energy by Raphael Katzen Associates (June 1979).

* The data were converted to first quarter 1980 costs. Plant size is 50 million gallons per year. The plant uses coal for processing energy.

a/ This conversion assumes 2.57 gallons of alcohol is produced from one bushel of corn.

b/ The fixed costs include amortization of the investment costs over 15 years at 15 percent rate of return plus license fees, maintenance, tax, and insurance. The capital cost including working capital is \$73.14 million.

c/ Operating costs include raw materials other than corn, such as energy, labor, overhead, freight and miscellaneous expenses.

d/ The by-products are distillers grains and ammonium sulfate. Distillers grains are valued at \$110 per dry ton and contribute 37 of the 38 cents by-product credit at \$2.50 corn. The distillers grain by-product credit in this table is calculated assuming that protein prices change along with corn prices. We assumed that three-fourths of the proportional change in corn prices occurs in DDG prices. For example, the change in corn price from \$2.50 to \$3.50 represents a 40 percent increase in corn prices, and we assume a DDG price of \$143, which is 30 percent higher than the \$110 base price.

The two prices tend to move in the same direction because corn and soybeans (a protein source) are grown in the same areas on the same type of land. However, the exact relationship between the two prices is not known, and this assumption represents our judgement as to what the relationship might be.

e/ This price includes profit for the producer (in the capital recovery component of fixed costs).

efficiency of the corn to ethanol conversion process. Does the process consume more energy than it actually produces? The answer to this question is unclear, and "creative accounting" or changes in assumptions can shift the results of the analysis from one conclusion to another. However, a number of large engineering firms claim to have energy efficient processes.

The results depend critically upon the assumptions made regarding: (1) the inclusion of crop residues in the analysis, (2) the processing or drying of by-products, (3) the vintage of technology used, (4) the efficiency of alcohol utilization in automobiles and (5) changes in the petroleum refining process which might be possible if alcohol could be used widely as an octane booster.

Most recent studies indicate that with new but currently available technology, the net energy output of alcohol used for gasohol balances or is perhaps somewhat greater than the input energy in growing,

transporting and processing the corn into alcohol.**

However, analyzing net energy may really ignore the most important factor that will influence national energy policy in the coming years. This is the need for liquid fuels, not just for net energy. It may not matter if ethanol production requires the same amount of energy, or even a bit more energy than is returned in the liquid product. Instead, the critical factor is whether we design our alcohol production capacity to run on solid energy forms like coal, which we have in abundance, rather than on oil or gas.

If federal subsidies encouraged the use of coal, the production of ethanol might be

** Two good sources for further information are: R. S. Chambers, R. A. Herendeen, J. J. Joyce and P. S. Penner, "Gasohol: Does It or Doesn't It Produce Net Energy," *Science*. Vol. 206, No. 4420 (Nov. 16, 1979); and Office of Technology Assessment, U.S. Congress, *Gasohol: A Technical Memorandum*, O.T.A., Washington, D.C., Sept. 1979.

viewed as an indirect way of converting coal to a liquid fuel. In our judgment, the federal subsidies should be denied to plants that burn oil or gas in the ethanol production process.

Some Policy Issues Involved

Beyond the complex issues discussed above lies an even more complex set of social policy issues dealing with energy and agriculture. We must strive to answer such questions as the following:

1. Many economists consider the cost to society of oil imports to be considerably higher than the private costs. How valuable is it to society to produce energy at home rather than to import it; and what is the best means to accomplish that objective?

2. What are the feedback costs of higher oil prices that go into the cost of producing corn and converting it to ethanol? Gasohol does not necessarily become economical when gasoline refinery prices reach over \$1.25 per gallon--because the cost of corn energy inputs in turn rise in price; thus, energy input costs in the conversion process rise in price.

3. What effects would various sizes of gasohol programs have on agriculture (in terms of corn and soybean prices, exports and farm incomes)?

4. What might be the consequences of alternative policies designed to stimulate production of energy from agriculture?

These and other questions remain unanswered, but research continues to focus on reaching answers.

FERMENTATION OF AGRICULTURAL BY-PRODUCTS INTO ALCOHOL

We now shift our focus to the use of agricultural by-products as input materials. The prospect of using agricultural by-products and other cellulosic residue materials to produce fuels such as ethanol and chemicals for industry holds some promise if the research and economics can be worked out. By cellulosic residues we mean corn stalks, sugar cane bagasse, waste paper and other municipal wastes and forestry products.

Presently, the United States produces approximately one billion tons of cellulosic waste materials each year, which theoretically could substitute for a large percentage of our liquid fuel needs. However, the question is not only availability of cellulosic materials, but also collectibility, conversion and the alternative value of these materials.

Of the approximately 400 million tons of agricultural crop residues produced each year, it is estimated that about 80 million tons should and could be removed from farm land for conversion to alcohol. This quantity of residue could potentially produce as much as 9.7 billion gallons of alcohol, about the same amount that could be produced from 50 percent of our corn crop.

Cellulose Conversion

Generally, cellulosic wastes contain three main components--hemicellulose, cellulose and lignin. Lignin is basically the cementing material of trees and other woody parts of the plant. Current residue utilization processes have had a very difficult time separating the protective lignin seal from the cellulose. Once made accessible, the cellulose can be used to produce alcohol by the traditional fermentation processes.

Several new processes for cellulose conversion are under development in the U.S. One of these is in the Laboratory of Renewable Resources Engineering (LORRE) at Purdue University under the direction of Dr. George T. Tsao. On a laboratory basis, the various approaches under development can convert one ton of cellulose into 0.8 ton of fermentable sugar. This involves converting each of the components of the cellulosic wastes into fermentable sugars and then into alcohols. Hemicellulose is converted to sugar first, and then the residual cellulosic material is pretreated and subsequently converted.

When comparing corn grain to corn crop residues, one ton of corn grain (35.7 bushels) can produce 0.65 ton of fermentable sugar from the starch portion. Using LORRE technology, 0.15 ton of fermentable sugar can be converted from the fiber in the grain, giving a total of 0.8 ton of fermentable sugar which is converted into 0.4 ton (120 gallons) of alcohol.

On the other hand, one ton of corn crop residue contains about 0.8 ton of fermentable sugar, which has a maximum potential yield of 0.4 ton (120 gallons) of alcohol. Potentially, as much alcohol could be produced from one ton of cellulosic wastes as can be produced from one ton of grain when using these new processes to convert cellulose into alcohol.

Crop Residue Harvesting and Handling

Another question to be answered involves removal of the crop residue from the field. To what extent does residue effect soil fertility and tilth? Research indicates that some cropland erodes badly enough so that no residue should be removed.

Crop residue removal also competes with harvesting and subsequent fall tillage. Therefore, more work must be done in identifying the optimum level of corn residue removal. A farmer with an opportunity cost of \$600 per hour for harvesting his grain is not likely to harvest crop residues at the rate of \$60-70 an hour if the grain and residue are competing for time. Equipment must be developed that can collect the waste material easily without interfering with the harvesting practice.

Yet another important problem is handling the residue. A profitable processing plant runs the entire year and therefore must have a continuous supply of crop residues. Crop residues will have to be handled very much like our grain or forage products are presently. That is, they must be collected and stored either as a dry or ensiled product in a system economically able to maintain quality and access for future transportation and processing. The transportation will have to be optimized in terms of how far it is economically feasible to transport these products. Many questions must be answered before we can proceed into the waste cellulose process.

Other sources of cellulosic waste materials include forest residues and municipal and industrial waste products. Although we may have a more constant supply of these products throughout the year to feed to a processing plant, the same questions concerning the economic feasibility, handling systems and equipment must be answered to design an efficient process.

Several other useful and high-priced products can also be made from grains and waste materials. Planning for research regarding utilization of waste materials and grains should include not only ethanol but also other chemicals. However, many technical and economic questions remain unanswered and constitute a major part of our current research efforts.

Alcohol Fermentation

Using sugars derived from starch or cellulose, the maximum yield is 1 pound of ethyl alcohol from each 2 pounds of fermentable sugar. The other half of the weight of sugar is given off as carbon dioxide.

It is desirable to obtain a concentration of ethanol in the fermentation broth of at least 6 percent. Below this concentration, the separation of ethanol from water by distillation becomes very energy-intensive. Current fermentation technology is capable of attaining up to 12 percent ethanol concentration in a reasonable fermentation time.

CONCLUSION

The heightened interest and activity in alcohol production for energy purposes is taking place in an environment where problems are looming larger and we are being pressed by world events for solutions to complex technical problems. Any new technology like cellulose conversion must go through a number of steps before it is applicable to full-scale commercialization and utilization. Even with the technology available, as in the case of alcohol production from corn, it takes substantial time and effort to capitalize and construct a new industry.

Our tendency is to want immediate "solutions" and to either accept or reject them on the first round of results. Uncritical acceptance based on positive results, or the equally likely rejection based on a first round of failures, does not give a technology the necessary time to develop and be proven. Either approach is likely to cause more harm than good. What is needed is less pressure for instant solutions and more patience for testing both new technologies that appear to work and those that still have to overcome many problems.